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REVIEW

Hybrid Open-endovascular Repair for Thoracoabdominal Aortic Aneurysms: Current Status and Level of Evidence

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Purpose. *To report the results of a systematic review of the literature and to provide evidence for the hybrid open-endovascular repair (HOER) in patients with thoracoabdominal aortic aneurysms (TAAAs).*
Methods. *A comprehensive literature review was performed and all studies identified that reported the results of HOER in patients with TAAA and information about primary technical and clinical success in evaluating the immediate and long-term complications such as neurological, renal and respiratory morbidity. All studies were reviewed by two independent observers for the above mentioned parameters.*
Results. *After careful selection according to the given criteria, 13 studies were included in our statistical analysis. The number of reported patients totalled 58. Of those, 37 were men (64.4%) and the mean age of the patients was 68.1 years (range 35–80, 95%CI [72.8, 64.9]). All patients were unfit for open repair with severe comorbidities. The mean follow-up period was 14.5 +/− 8.7 months (range 4–36, 95%CI [18.7, 9.9]) and the mean aneurysm diameter was 7.15 cm (range 5 to 12, 95%CI [7.87, 6.69]). 229 (97.8%) of the 234 visceral vessel grafts remained patent during the follow-up period. Reintervention was necessary in one (1.6%) of the five patients with an occluded graft. The overall long-term endoleak rate was 20.6% (12/58 patients) and the reintervention rate was 13.7% (8/58 patients). No patients developed procedure-related neurological deficits. The overall early and long-term mortality rate for completed procedures was 15.5% (9/58).*
Conclusions. *HOER shows promising mid-term results for high-risk patients who have TAAA, however, present evidence does not allow robust conclusions.*

Keywords: Hybrid; Open-endovascular repair; Thoraco-abdominal aortic aneurysm; Systematic review.

Introduction

In recent years, advances in surgical techniques and organ protection methods have led to better outcomes for the open repair of thoracoabdominal aortic aneurysms (TAAA), but severe neurological, renal and respiratory morbidity still occur in some patients.[1,2]

In 1991 Parodi[3] reported the endovascular repair of abdominal aortic aneurysms and ushered in the endovascular era in the treatment of aneurysms. In 2001 Chuter[4,5] described the first case of total endovascular repair of TAAA, complicated by spinal cord ischemia. Inability to preserve intercostal artery perfusion, the time-consuming nature of the procedure and the exposition of the vascular specialist to high radiation doses remain severe disadvantages of the fenestrated and branched stent-grafts.

The hybrid open-endovascular repair (HOER), i.e. open visceral vessels debranching and subsequent endovascular exclusion of the TAAA, offers a possible alternative treatment option for patients who are unfit for the open repair or who have unfavourable anatomy for total endovascular therapy.

We performed a systematic review focusing on the primary and follow-up technical and clinical success of HOER in terms of neurological, renal, respiratory morbidity, graft durability and endoprosthesis-related complications.

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Patients and Methods

Search strategy

An extensive search of the literature published between January 1999 and October 2006 was performed using PubMed. Additionally, the reference lists of all included articles were examined for further relevant references. A further search of relevant general medical and specific journals was conducted by hand. All studies were independently assessed by 2 reviewers for inclusion and exclusion criteria and the full text of these studies were retrieved.

Study eligibility

Studies were included if the following criteria were fulfilled: (1) TAAA was diagnosed on the basis of the Crawford classification, modified by Safi, (2) HOER (visceral bypass followed by endovascular stent-graft implantation) was the intended repair strategy and was completed in all patients, (3) there had been a minimum follow-up period of 4 months, (4) diagnosis of complex TAAA had been made according to computed tomographic (CT) scans of the thorax, abdomen and pelvis, (5) at least one of the basic outcome criteria (neurological, renal, respiratory morbidity, visceral vessel patency and endoprosthesis related complications, as well as the primary technical success rate, and the total mortality rate were stated. Articles were excluded if TAAA repair was only by surgical or endovascular approaches alone.

Data extraction and analysis

For each study the following data were extracted by two independent reviewers: number of patients, sex, mean age (years); primary technical success; 30 days clinical success; stentgraft design; mean follow-up period (months); neurological, renal, respiratory morbidity; visceral vessel patency and endoprosthesis related complications; reinterventions and the procedure- related and total follow-up mortality. Where disparate results were reported by the two observers extracting the data, the publications were re-analyses and consensus reached. Primary technical success and 30-day clinical success included events which occurred within the first 24 hours and 30 days after intervention, respectively.

Patient selection criteria

The patients were all deemed unfit for open surgical approach. This category included patients who could not tolerate aortic cross-clamping or open thoracotomy due to prior aneurysmal repairs and/or having severe medical comorbidities, such as chronic obstructive disease (COPD), coronary artery disease (CAD), congestive heart failure (CAF), diabetes mellitus (DM), and hypertension (HN). None of these patients was an exclusively endovascular candidate, due to marked arterial tortuosity, severe angulation of the aorto-iliac system, or involvement of the aortic side branches in the aneurysm. Patients who suffered from isolated aortic arch or descending aneurysms, acute or chronic aortic dissections or traumatic transactions and connective tissue disorders, such as Marfan syndrome and Ehlers-Danlos syndrome were excluded from the study. Additionally, cases with aortic para-anastomotic pseudoaneurysm after previous surgical repair of TAAA were not included in the present review.

The definition of the TAAA was made according to the Crawford classification, modified by Safi.[7] Type I TAAA extends from the proximal descending aorta to the upper abdominal aorta; Type II TAAA from the proximal descending thoracic aorta to below the renal arteries; Type III TAAA from the distal half of the descending thoracic aorta into the abdomen; Type IV involves the majority of the entire abdominal aorta. In 1999, Safi added a fifth type to the origin four which extends from the 6th intercostals space to just above the renal arteries.

Statistical analysis

All numeric values are stated as mean +/− standard error in parenthesis.

Results

Our electronic literature search identified 27 studies. After additional searches by hand and careful selection in accordance with the inclusion criteria, 13 studies[9–21] were included in our statistical analysis. Detailed data is provided in Table 1. The number of reported patients totalled 58. Of those 37 were men (64.4%) and the mean age of the patients was 68.8 years (range 35–80, median 69.6, 95%CI [72.8, 64.9]). 15 TAAAs were of type I, 21 of type II, 11 of type III, 6 of type IV and 5 of type V. The mean follow-up period was 14.3 +/− 8.4 months (range 4–36, median 12 months, 95%CI [18.7, 9.9]) and the mean aneurysm

Table 1. The studies about "completed hybrid procedure for patients with TAAAs" which were included in the review-analysis

Authors	Year	Location	fu	*n*	0–30 d mortality
Black *et al.*	2006	London/UK	8	26	6
Flye *et al.*	2004	St.Louis, Mo/USA	14.6	3	0
Donas, *et al.*	2007	Cologne/Germany	21	8	1
Chiesa, *et al.*	2004	Milan/Italy	12	1	0
Macierewicz, *et al.*	2000	Nottingham/UK	22	1	0
Quiñones-Baldrich, *et al.*	1999	LA, Calif/USA	6	1	0
Lawrence-Brown, *et al.*	2000	Perth/Australia	36	2	0
Kotsis, *et al.*	2003	Ulm/Germany	14	4	1
Agostinelli, *et al.*	2002	Parma/Italy	6	1	0
Iguro, *et al.*	2003	Kagoshima/Japan	12	1	0
Saccani, *et al.*	2002	Parma/Italy	4	3	1
Khoury, *et al.*	2002	Detroit/USA	21	1	0
Gawenda, *et al.*	2006	Cologne/Germany	12	6	0

fu- follow-up, *n*-number of patients.

diameter was 7.15 cm (range 5 to 12, median 7.5 cm, 95%CI [7.87, 6.69]).

Primary technical, 30-days clinical success and long-term clinical outcome

Primary technical success was achieved in all 58 patients (100%). The most commonly used stent-graft designs were Talent ($n = 25$, Medtronic, Inc.; Minneapolis, Minn), Excluder ($n = 16$, W. L. Gore & Associates, Newark, DE, US), Zenith ($n = 5$, Cook Endovascular, Bloomington, IN, US), Gianturco stainless-steel Z ($n = 5$, Cook Group, Inc, Bloomington, Ind), Jotec E-vita ($n = 1$, Jotec, Hechingen, Germany), Corvita Endoluminal Graft (CEG) Tubular Aortic Endoprosthesis ($n = 1$, Schneider, Minneapolis, Minn), and Talent stent-grafts combined with Excluder grafts (used in 3 patients). For two patients no specific name of the device type was reported in the published cases (Table 2). During the first 30 days after the hybrid procedure graft-related complications were reported in 11 patients (18.9%). Six patients had type I endoleaks (10.3%), four had type II endoleaks (6.8%) and one patient had a type III endoleak (1.7%). Of the eleven patients who had initial type I endoleaks 5 (8.6%) required an early reintervention and one developed another type I leak at 1 year, all of which were corrected via stent extensions. These procedures resulted a decrease in the size of the leak and stable sized aneurysm sac. One patient with distal type I endoleak (IB) was successfully treated with embolization. For the patients with type II endoleak, all except one had resolved on CT scan at 3 months. The latter patient required occlusion coiling of the left subclavian artery origin. The overall long-term endoleak rate was 20.6% (12/58 patients) and reintervention was required in 13.7% of the patients (8/58 patients).

Table 2. The most commonly used stent-graft designs for the endovascular exclusion of the thoracoabdominal aortic aneurysm

Stent-graft devices	*n*
Talent (Medtronic, Inc.; Minneapolis, Minn)	25
Excluder (W.L. Gore & Associates, Newark, DE, US)	16
Zenith (Cook Endovascular, Bloomington, IN, US)	5
Gianturco stainless-steel Z (Cook Group, Inc, Bloomington, Ind)	5
Jotec E-vita (Hechingen, Germany)	1
Corvita (Schneider Minneapolis Minn)	1
Talent + Excluder	3
Unknown	2

n: number of stent-graft devices.

Graft patency

At a mean follow-up of 14.2 months (median 12 months, range, 4 to 36 months), 229 (97.8%) of the 234 hybrid surgical grafts remained patent (Table 3). The superior mesenteric artery (SMA) graft occluded in two patients and a single renal graft occluded in another three. Further intervention was necessary in one (1.6%) of the five patients with the occluded grafts due to poor collateral supply of the SMA and the development of progressive ischemic colitis. The SMA graft thrombectomy was successful and the patient's post-operative course proved uneventful. With regards to the other cases, one patient with SMA graft occlusion showed good collateral supply via the celiac artery and for the three patients with single renal graft thrombosis, the patient's other kidney remained in good condition with a good functioning graft, and no further intervention was pursued.

Morbidity

No patients developed paraplegia or other procedure-related neurological deficits due to spinal cord injury and ischemia. Two (3.4%) patients who underwent renovisceral rebranching and subsequent endovascular exclusion of the aneurysm distal to the left subclavian artery were found to have left hemispheric emboli postoperatively with total resolution of hemiplegic symptoms in both before discharge. Major adverse events included prolonged respiratory support (>5 days) in 11 patients; prolonged inotropic support (>4 days) in 4; renal impairment (eg > 25% rise in creatinine) requiring temporary haemodialysis

Table 3. Visceral vessel grafts and patency rate during the follow up period

Graft	Aorto-renal	Aorto-mesenteric	Aorto-celiac	Iliaco- mesenteric	Iliaco-celiac	Iliaco-renal
Total	117	50	43	7	7	10
Occluded	3	2	0	0	0	0
Primary graft- patency	97.4%	96%	100%	100%	100%	100%

in 3 and not requiring support in 2; ischemia of the left colon requiring resection in 1, and prolonged ileus (>7 days) in 3. In one further patient with an extensive isolated type II TAAA secondary to a chronic type B dissection, a type A dissection developed 10 days after the initial procedure and required an emergency Bentall procedure. Another patient from the Cologne patient-group[11] had a myocardial infarction 3 days after the operation. Cardiac enzymes and ECG changes returned to normal within a further 3 days. In summary, 28 (48.2%) patients had a major complication after the combined procedure during their hospital stay.

Mortality

Thirty-day elective and urgent mortality was 10.7% (6/55). Three patients with a ruptured TAAA who underwent the HOER died. The overall early and long-term mortality for completed procedures was 15.5% (9/58). One patient (1.7%) developed ischemic-related pancreatitis and did not respond to conservative treatment. The patient died on the 6th postoperative day (POD) following multiorgan failure. Immediate postoperative diffuse retroperitoneal bleeding occurred in one patient (1.7%). The patient developed multiorgan failure. Another patient died from pulmonary embolus on day 29 and one died as a result of myocardial infarction on day 10. The fifth patient underwent embolization after placement of visceral revascularization grafts. It is unclear if this complication occurred after the passage of the stent-grafts through the iliac system that supported the renovisceral rebranching. The emboli resulted in widespread microinfarction in all the visceral beds. The last patient from the elective and urgent group who died had intestinal bleeding and bowel infarction of unknown aetiology on the 12th POD.

From the three patients with ruptured TAAAs, one died intraoperatively and two survived >10 days postoperatively only to succumb to cardiac complications.

Two late complications occurred due to procedure unrelated causes such as a ruptured ascending aortic aneurysm 3 months after the operation in one case and cardiac disease 3 years after the combined approach in the other case.

Discussion

The results of elective surgical repair of TAAA have improved considerably over the last 20 years. For example, 30-day mortality rate of 5.7%, paraplegia rate of 4.5% and renal failure requiring dialysis of 6.0% were recently reported.[7] Nevertheless, there are several disadvantages to open TAAA repair including[6–8] extensive incisions for aneurysm exposure, temporary aortic and visceral vessel occlusion, and the replacement of long segments of the aorta. Several adjuncts have been developed for open TAAA, including different types of shunts, pumps (for peripheral perfusion) and continuous neurological monitoring.[8]

Ultimately, cord injury after aortic surgical replacement results from an ischemic insult that is caused by temporary or permanent interruption of spinal cord blood supply. Consistent with the hypothesis that the duration of ischemia is an important predictor of cord complications, the risk of treatment-related cord injury clearly increases with the more extensive TAAA types, i.e. types I and II. Svensson,[22] detailing Crawford's open repair experience with more than 1500 patients with TAAA, noted a 24% incidence of cord injury in types I and II TAAA, as compared with 5.5% for types III and IV.

The sustained development of the endovascular treatment of aneurysms made possible a combined surgical and endovascular approach known as the "hybrid procedure" for extensive TAAAs. This approach reduces the open procedural burden by avoiding extensive thoraco-abdominal access.[9,11,16] In addition, the total avoidance of high aortic cross clamping allows a significant reduction of visceral and renal ischemia time, which influences the appearance of severe complications such as renal impairment and dialysis.[11] Moreover, the performance of the procedure under hemodynamically stable conditions reduces the risk of neurological complications, such as paraplegia and/or paraparesis.[11]

The literature provides scant information regarding the immediate and long-term results of HOER in patients suffering from TAAA, mostly in the form of case reports and small patient series. Therefore, this systematic review aims to demonstrate the results of the published series under inclusion criteria and to draw conclusions about the efficacy of

the HOER in TAAAs. In spite of 61% (36/58) of the included patients treated with HOER having type I and II TAAAs, there was no evidence of paraparesis or paraplegia in any of the reported cases. This finding has also been described in the series involving a complete endovascular approach.[3,4] The exclusion of several factors using the combined technique, facilitating the development of spinal cord ischemia, such as intraoperative haemodynamic instability, reperfusion injuries with postoperative cord oedema linked to a compartment-like syndrome within the rigid confines of the bony canal and, of course, aortic cross-clamping are likely important in the reduced neurological complication rate. Recently, there has been a report of a patient who underwent HOER suffering from paraplegia and transient paraparetic events postoperatively.[23]

The results of the primary graft patency rates are very encouraging. At a mean follow-up of 14.2 months, 229 (97.8%) of the 234 grafts remained patent. The superior mesenteric artery (SMA) graft occluded in two patients and in only one (1.7%) of all patients was a reoperation necessary, i.e. SMA bypass thrombectomy so as to prevent severe ischemic colitis. Routes of visceral revascularisation are controversial but if a retrograde visceral revascularization technique is used then it is ideal to pass the stent graft via the contralateral iliac artery.[8,11]

The Achilles heel of the endovascular stent-graft placement remains endoleaks. Dealing with proximal type I endoleaks by use of proximal stent extension requires the adjunctive transpositioning of vessels of the aortic arch so as to create the necessary landing zone for the thoracic endografts. Nevertheless, in spite of crossover grafting it has been reported that with the persistence of proximal type I endoleaks, there remains the potential risk of rupture of the thoracic aneurysm segment.[8]

Eleven patients (18.6%) of the 58 showed initial endoleaks. Six patients had type I endoleaks (10.3%), four had type II endoleaks (6.8%) and one patient type III endoleak (1.7%). At 1 year after the HOER another patient developed a type I leak. Correction was necessary in 6 cases by stent extensions. One patient underwent carotid-carotid/subclavian crossover grafting to create the necessary landing zone. The high incidence of endoleaks reflects the difficulty in creating an adequate landing zone for the graft and probably the inappropriate design of current stent-graft for extensive TAAAs.

The majority of the authors prefer to use the lower aorta or common iliac artery for the origin of the retrograde grafts. The results of the review justifies this attitude because only 2 (3.4%) patients of the 58 developed a distal type I endoleak and in only one (1.7%) of them required treatment.

Even though, the number of patients with TAAA treated by HOER is still low, and the period of follow-up short, the preliminary results are encouraging. The absence of severe neurological deficits in the reported case histories clearly demonstrates the prevention of spinal cord injury due to the avoidance of cross clamp-induced spinal cord ischemia. Nevertheless, further studies are necessary to draw definitive conclusions.

Conclusion

The present systematic review shows promising midterm outcomes for high-risk patients with TAAA who underwent hybrid procedures (visceral bypass followed by endovascular stent-graft implantation). However, there is little data in the literature to support the combined technique as better, worse, or equivalent to the open repair or simply medical treatment alone. Thus, the continued development of the endovascular technologies and increasing experience in the combined procedure are paramount to draw robust conclusions about the suggested alternative treatment option in patients with challenging TAAAs.

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